# Whole body concentration ratio of $^{137}$Cs, $^{85}$Sr and $^{65}$Zn for Chinese minnow (*P. oxycephalus*) and earthworm (*E. andrei*)

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**Abstract.** The whole body concentration ratio (CR) of $^{137}$Cs, $^{85}$Sr and $^{65}$Zn for Chinese minnow (*P. oxycephalus*) and earthworm (*E.andrei*) were experimentally measured in a laboratory. The mean CR (Bq /kg fresh per Bq/l) of Chinese minnow was 3.5 for $^{137}$Cs, 11.0 for $^{85}$Sr, and 9.8 for $^{65}$Zn, respectively. The mean CR (Bq /kg fresh per Bq/kg) of earthworm was $4.4 \times 10^{-4}$ for $^{137}$Cs, $1.7 \times 10^{-3}$ for $^{85}$Sr, and $1.4 \times 10^{-3}$ for $^{65}$Zn, respectively.

## 1. INTRODUCTION

Non-human biota dose assessment is necessary to verify that ecosystem is being well protected from the ionizing radiation [1]. Concentration ratio (CR) is an essential parameter for assessing the radiation dose of non-human biota. The concentration ratio for aquatic and terrestrial biota is generally defined as

$$CR = \frac{\text{Activity of biota (Bq/kg F.W.)}}{\text{Activity of water or soil (Bq/l or Bq/kg soil)}} \quad (1)$$

There have been many efforts to derive CR values for wildlife. IAEA (international Atomic Energy Agency) is developing the handbook of parameter

values for prediction of radionuclide transfer to wildlife through a peer review process by experts within the EMRAS (Environmental Modeling for Radiation Safety) international joint program [2]. ICRP (International Commission on Radiological Protection) is preparing a report for transfer parameters for the reference animals and plants presented its 2007 new recommendation [3]. Beresford et al.[4] and Hosseini et al.[5] presented the default transfer parameters for terrestrial and aquatic biota through comprehensive literature survey for use within the ERICA assessment tool. However, there is still much lack of CR data for many wildlife and radionuclides as well as there is a large uncertainty as exhibiting the CR value of wide range even for the same biota. The CR for the small freshwater fish and earthworm that is one of key components in water and in soil, respectively, is available in very limited references.

This paper describes the experimental method to obtain the whole body concentration ratio of $^{137}$Cs, $^{85}$Sr and $^{65}$Zn for the Chinese minnow (*P. oxycephalus*) and the earthworm (*E.andrei*), and discusses the measured CR results for the both biota.

## 2. MATERIALS AND METHOD

### 2.1 Chinese minnow

For the uptake experiment of radionuclides by a small freshwater fish, the Chinese minnow (P. oxycephalus), which is a very plentiful fish found in river and lake in the Republic of Korea, was selected. Adult and youngish minnows were purchased from a commercial nursery, and they were bred together in a small plexiglass aquarium (45cm x 85cm x 50cm) that was equipped with the lid to prevent the evaporation of water (Figure 1). Before the start of experiment, the source solution spiked with $^{137}$Cs, $^{85}$Sr, and $^{65}$Zn were evenly treated on the water body in the aquarium by using micropipette. The fishes were fed two times a day, and air was continuously blown through the vinyl tube at bottom of the aquarium to supply oxygen into water. The sampling period of fish and water was shorter for the initial time of experiment, and was longer for the late time. At each sampling, about 4 to 5 fishes (about 20 to 30g on the basis of fresh weight) were captured. The sampled fish was dried at 80°C in oven during 2 to 3 days, and was crushed without distinguishing between organs to measure the whole body activity. The radioactivity of the crushed fish sample was measured by the gamma spectrometer equipped with NaI detector. The counting error was

within 5%. At the same time of fish sampling, the pH and temperature were also measured. There was no control of pH and temperature of water. Duplicate experiments were carried out by using two aquariums. Changes of water activity, fish activity, and CR with time were investigated.

(a) aquarium

(b) dried fish sample

**Figure 1.** Experimental apparatus (a) and dried fish sample for CR measurement of minnow

### 2.2 Earthworm

Figure 2 shows the experimental procedure for the CR measurement of earthworm. The soil was sampled from the field near the Gyeongju repository, in the Republic of Korea. The sampled soil was passed through 0.5cm sieve and was dried before the use in the experiment. To make the contaminated soil for use in the experiment, the source of $^{137}$Cs, $^{85}$Sr, and $^{65}$Zn were first treated in 20kg dried soil, and subsequently the soil was well mixed by using the V-type soil mixer for the uniform distribution of radionuclide in soil. The uncontaminated and dried manure of 4kg was added in the contaminated soil for the food of earthworm, and the water of 9kg was added to keep a wet condition that was equivalent to the soil moisture of about 0.27. The earthworm was purchased from a commercial dealer a few days before the start of the experiment. At the beginning of the experiment, about 1kg earthworm was put at 10cm depth below soil in the plexiglass box (30cm x 20cm x 60cm). The outer surface of the plexiglass box was coated with a thin film of black color to prevent the worm from exposure to light. The earthworm and soil was sampled

with the interval of a week for eight weeks. At each sampling time, earthworm of about 50g was picked up evenly over the soil by using tweezers. The sampled earthworm was put on filter paper to clear its gut for 24 hours. And it was washed to remove the soil particle on the earthworm skin by the distilled water, and was dried at the room temperature. The dried earthworm was completely dissolved in HCl solution to prepare the homogeneous liquid sample for the activity measurement by using the gamma spectrometry with NaI detector. Counting time was set to obtain a counting error less than 5%. Duplicate experiment was carried out by using two parallel soil boxes.

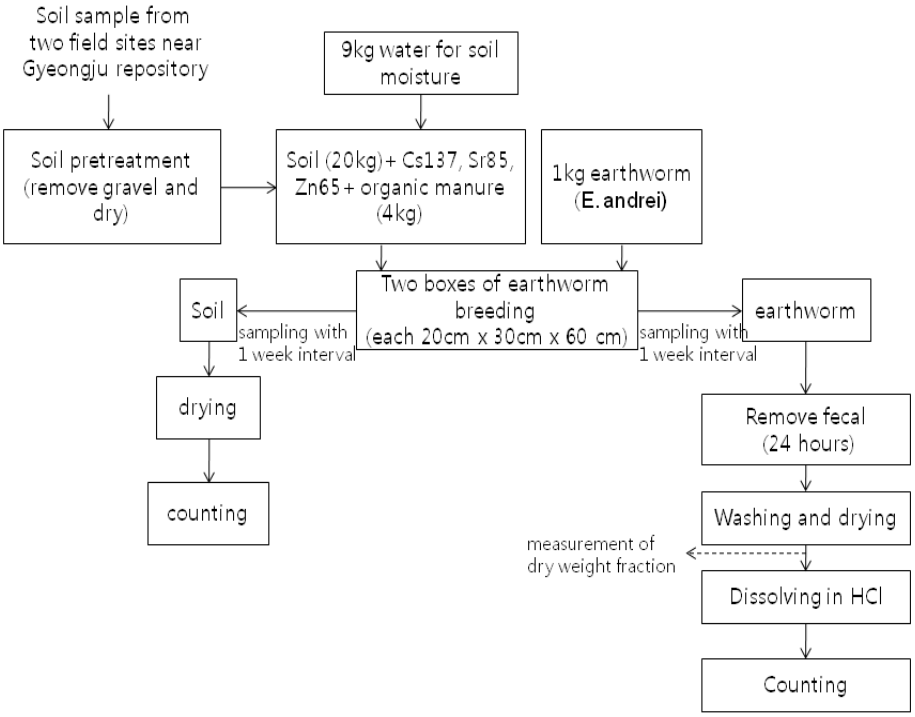


**Figure 2**. Experimental procedures for the CR measurement of earthworm

## 3. RESULTS AND DISCUSSION

### 3.1 Minnow

The observed pH and temperature of water in the aquarium during the experiment ranged from 6.9 to 7.5, and from 20 to 25°C, respectively, indicating that the water kept good condition for the fish breeding. The dry weight fraction

of the Chinese minnow was calculated by the difference in the weight between the fresh and dried fish. The calculated dry weight fraction of the fish was about 0.23, which was mean value of total 18 fish samples (9 samples for each aquarium).

The measured whole body CR for the Chinese minnow was summarized in Table 1. For all of three radionuclides, the CR values were gradually increased with time until about 25 days even though they exhibited some fluctuation, but the increased rate of values was considerably fallen after 25 days. This result may explain that the transfer of radionuclide between water and fish had almost reached at equilibrium after about 25 days. The mean CR value of Chinese minnow at 32 days obtained from two aquariums was 3.5l/kg for $^{137}$Cs, 11.0l/kg for $^{85}$Sr, and 9.8 l/kg for $^{65}$Zn, respectively. The CR of $^{137}$Cs and $^{65}$Zn was about three orders of magnitude less than those of the freshwater fish in the IAEA draft handbook [1]. The CR of $^{85}$Sr was similar to the CR value of pelagic fish in the ERICA data base [5], while it was less by a factor of about 100 than the fish CR in the IAEA draft handbook.

Table 1. Whole body concentration ratio (Bq/kg fresh per Bq/l) of the Chinese minnow

| time (days) | | 1 | 2 | 4 | 6 | 9 | 14 | 19 | 25 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|
| Aquarium A | $^{137}$Cs | 0.08 | 0.23 | 0.41 | 0.69 | 0.78 | 1.28 | 2.18 | 2.68 | 2.98 |
| | $^{85}$Sr | 0.35 | 0.72 | 1.19 | 1.61 | 1.40 | 2.62 | 4.87 | 6.27 | 8.03 |
| | $^{65}$Zn | 0.48 | - | 2.02 | 1.77 | 1.03 | 2.29 | 6.55 | 7.30 | 6.59 |
| Aquarium B | $^{137}$Cs | 0.12 | 0.38 | 0.46 | 0.97 | 1.72 | 2.06 | 0.13 | 3.99 | 3.95 |
| | $^{85}$Sr | 3.94 | 1.17 | 1.60 | 1.86 | 4.20 | 5.39 | 0.18 | 12.26 | 13.91 |
| | $^{65}$Zn | 0.53 | 1.70 | 1.94 | 3.75 | 4.87 | 9.04 | 1.08 | 11.55 | 13.08 |
| arithmetic mean of A and B | $^{137}$Cs | 0.1 | 0.3 | 0.44 | 0.83 | 1.25 | 1.67 | 1.15 | 3.34 | 3.47 |
| | $^{85}$Sr | 2.15 | 0.95 | 1.4 | 1.74 | 2.80 | 4.0 | 2.52 | 9.26 | 10.97 |
| | $^{65}$Zn | 0.5 | 1.70 | 1.98 | 2.76 | 2.95 | 5.66 | 3.82 | 9.43 | 9.84 |

### 3.2 Earthworm

The weight of earthworm after clearing gut was measured to calculate the dry weight fraction. The calculated dry weight fraction ranged from 0.1 to 0.19. Its average value of 12 samples (6 samples from each box) was about 0.15, which is comparable to values in the other works (0.17 for the soil invertebrates in the

ERICA database [4], and about 0.14 in Janssen et al. [8]). Over the experimental period, no change of the soil radioactivity was found. The measured soil activity was $2.8x10^5$ ±5% Bq/kg for $^{137}Cs$ and $^{85}Sr$, and $2.8x10^4$ ±5% Bq/kg for $^{65}Zn$, which was almost same as the initial soil activity. Without any meaningful trend with time, the activity of earthworm ranged from 92 to 150 for $^{137}Cs$, from 340 to 650 for $^{85}Sr$, and from 22 to 55 for $^{65}Zn$, respectively.

The whole body concentration ratio for the earthworm is summarized in Table 2. The average CR obtained from two soil boxes ranged from $2.3x10^{-4}$ to $5.3x10^{-4}$ for $^{137}Cs$, from $1.2x10^{-3}$ to $1.9x10^{-4}$ for $^{85}Sr$, and from $7.7x10^{-4}$ to $1.9x10^{-3}$ for $^{65}Zn$, respectively. The average of all samples was $4.4x10^{-4}$ for $^{137}Cs$, $1.7x10^{-3}$ for $^{85}Sr$, and $1.4x10^{-3}$ for $^{65}Zn$. The CR value of $^{137}Cs$ was about two orders of magnitude lower than that obtained from other works [4, 6 and 7], and the CR value of $^{85}Sr$ and $^{65}Zn$ was less by a factor of 10 than the result by Yoshida et al.[7]. The lower CR values of the present work were likely to be attributed to two reasons. First, the total activity in soil was much larger than the amount ingested by earthworm. For example, the total activity of $^{137}Cs$ ingested by the worm was no more than 0.003% of total activity in soil. Consequently, very high soil activity compared to the activity of earthworm resulted in a low CR value. On the point of view of dose evaluation, this result implies a need for a careful approach when the radiation dose estimation for biota in a highly contaminated soil is performed. If the CR value obtained from a low contaminated soil would be used for the dose estimation of biota living in a high contaminated soil, the dose could excessively overestimated. The other possible reason on the lower CR was that the uncontaminated manure was used for food of the worm. The uptake of radionuclide by the worm was limited as the radionuclide was mainly on the soil particle, and consequently it led to the reduction of the bioaccumulation of radionuclides in the worm.

Table 2. Whole body concentration ratio (Bq/kg fresh per Bq/kg) of the earthworm after clearing gut

| time (days) | | 7 | 14 | 21 | 28 | 35 | 58 |
|---|---|---|---|---|---|---|---|
| Soil 1 | $^{137}Cs$ | 4.64E-04 | 2.40E-04 | 5.84E-04 | 6.29E-04 | 4.33E-04 | 4.32E-04 |
| | $^{85}Sr$ | 1.93E-03 | 1.09E-03 | 2.25E-03 | 1.44E-03 | 1.30E-03 | 1.48E-03 |
| | $^{65}Zn$ | 7.28E-04 | 7.37E-04 | 1.74E-03 | 1.42E-03 | 1.54E-03 | 1.89E-03 |
| Soil 2 | $^{137}Cs$ | 1.95E-04 | 2.23E-04 | 5.13E-04 | 3.86E-04 | 5.93E-04 | 6.41E-04 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $^{85}$Sr | 1.79E-03 | 1.34E-03 | 2.37E-03 | 1.58E-03 | 1.74E-03 | 2.39E-03 |
| | $^{65}$Zn | 8.22E-04 | 8.61E-04 | 1.94E-03 | 1.39E-03 | 1.83E-03 | 2.01E-03 |
| arithmetic mean of soil 1 and 2 | $^{137}$Cs | 3.30E-04 | 2.32E-04 | 5.49E-04 | 5.08E-04 | 5.13E-04 | 5.36E-04 |
| | $^{85}$Sr | 1.86E-03 | 1.21E-03 | 2.31E-03 | 1.51E-03 | 1.52E-03 | 1.94E-03 |
| | $^{65}$Zn | 7.75E-04 | 7.99E-04 | 1.84E-03 | 1.40E-03 | 1.69E-03 | 1.95E-03 |

## 4. CONCLUSION

The whole body concentration ratio (CR) of $^{137}$Cs, $^{85}$Sr and $^{65}$Zn for Chinese minnow (*P. oxycephalus*) and earthworm (*E.andrei*) were experimentally measured in a laboratory. The mean CR (Bq /kg fresh per Bq/l) of Chinese minnow was 3.5 for $^{137}$Cs, 11.0 for $^{85}$Sr, and 9.8 for $^{65}$Zn, respectively. The mean CR (Bq /kg fresh per Bq/kg) of earthworm was $4.4\text{x}10^{-4}$ for $^{137}$Cs, $1.7\text{x}10^{-3}$ for $^{85}$Sr, and $1.4\text{x}10^{-3}$ for $^{65}$Zn, respectively. The present CR values were wholly lower than those obtained from other works, which was mainly ascribed to a very high activity in the water and soil compared to the amount of uptake by biota. At present, the CR value for the earthworm living in the soil of lower activity are being studied, and the result will be available soon.

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